Nanotechnology

Topics Covered

→ Applications of nanomaterials
→ Quantum Confinement
→ Properties of nanomaterials
→ Synthesis of nanomaterials
→ Ball Milling and Sol-gel method

Important Formula

For a particle [spherical in shape]

$$\frac{\text{Surface}}{\text{Volume}} = \frac{3}{r}$$

where r is the radius of particle.

The materials having at least one external dimensional or internal structure, in range of 1-100 nm, are known as nanomaterials.

Nanotechnology is the branch of science and engineering that deals with the design, manipulation and application of materials at the nanoscale [1-100nm].

Why nanotechnology?

As the dimension or size of material approaches nano-scale, there are more and more particles available on surface then in the volume. Because of this increase in surface area available for interaction materials show unique electrical, optical, magnetic

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and mechanical properties.

→ Also at nanoscale, quantum effects come into picture.

Applications of nanotechnology

① Medicine and healthcare :- Used in targeted drug delivery, cancer therapy, medical imaging and biosensors for early disease detection.

② Electronics and nanoelectronics: Enables fabrication of smaller, faster and energy efficient transistors, processors and memory devices

③ Energy Storage and conversion: Improves efficency of solar cells, lithium-ion batteries, fuel cells and supercapacitors.

④ Environmental protection: Nanomaterials are used in water purification, air filtration and removal of toxic pollutants.

⑤ Material science and nanocomposites: Produces lightweight high strength, wear-resistant materials for aerospace and automobiles.

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(6) Textiles and coatings: Used to develop self-cleaning, anti-bacterial, UV-resistant and stain-free fabrics and surfaces.

(7) Food and agriculture: Applied in smart packaging, nano-fertilizers, pesticides and detection of food contamination.

(8) Sensors and instrumentation: Nanosensors provide high sensitivity for detecting gases, chemicals and biological molecules.

(9) Cosmetics and personal Care: Nanoparticles are used in suscreen, creams and lotions for better absorption and protection.

(10) Defense and security: Used in lightweight armor, stealth materials, explosives detection and advanced surveillance systems.

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Bulk Materials

These are the materials in which the physical and chemical properties are independent of size and shape and remain the same as the materials dimensions

are large compared to atomic or nanoscale.

→ These materials are dominated by volume effects unlike nanomaterials which are dominated by the surface effects.

Quantum Confinement

Quantum confinement is the restricted motion of randomly moving electrons in specific energy levels when the dimension of a material approach the deBroglie wavelength of electron.

→ Quantum confinement leads to change in optical and electrical properties. The change in properties occur because of the energy levels becoming discrete.

→ Based on the number of dimensions that are confined, nanostructures are classified as 3D [Bulk materials]; 2D [Quantum Well], 1D [Quantum Wire], 0D [Quantum Dot].

Quantum Well [2D]

When electrons are confined in a way that they are free to move in two dimensions but third one is restricted for motion by reducing the materials one dimensions in nano-range is known as Quantum Well.

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→ Example: Nano thin-film

[It has thickness in nano-range, which makes it very-very thin]

Quantum Wire

When electrons are confined in a way that they are free to move in only one dimension but other two are restricted for motion by reducing the material two dimensions in nano-range is known as quantum-wire.

→ Example: Carbon nanotubes.

[Electrons move only along the length]

~~Quantum Wire~~ Quantum Dot

When all the three dimensions of a material are reduced in nano-range, such that electrons motion is restricted in all three dimensions, is known as quantum dot.

Example: Fullerene

[Electrons are restricted at a dot]

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Properties of Nanomaterials

① **Large surface area to volume ratio:**
As particle size decreases to nano-scale, a large fraction of atoms are available on the surface for interaction. This leads to increased reactivity, catalytic efficiency and surface energy.

② **Quantum size effects:** Due to confinement of electrons in very small dimensions as material size is reduced to nano-scale, the materials electronic and optical properties are altered. This leads to a change in colour and conductivity as compared to bulk materials.

③ **Achieving superhydrophobic surfaces:** Due to the roughness in nanoscale surfaces, the properties like hydrophobicity or hydrophilicity is enhanced in materials. This phenomenon relies on achieving Cassie-Baxter state which allows support of water droplet on nano-roughness.

④ **Superparamagnetic materials:** When a ferromagnetic

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material ~~cracking~~ [which consists of magnetic domains] particle size is reduced to nanoscale range, the earlier domains break down. Due to this, entire particle becomes a single domain. The spins are randomly aligned and align in direction of magnetic field on external application, behaving like a super paramagnetic material.

(5) Enhanced mechanical properties: Increased strength, hardness and wear resistance compared to bulk materials.

(6) Altered thermal and chemical properties: The chemical and thermal properties are modified due to high surface to volume ratio.

(7) Modified electrical properties: Electrical conductivity can increase or decrease due to electrons confinement and tunelling effects.

(8) High catalytic efficency: Nanoparticles act as efficient catalysts because of increased active surface sites.

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Synthesis of Nanomaterials

There are two techiques used for making nanomaterials.

① Top-down method: [Going from higher particle size to nano-range]

Ex:- Ball-Milling,

② Bottom-up method: [Going from lower particle size to nano-range]

Ex: Sol-gel method

Ball Milling Method

It is a top-down mechanical technique in which bulk materials are broken down into fine and ultrafine particles by repeated impact and friction between hard balls and the material inside a rotating mill.

Sol-gel Method

It is a bottom up method used for synthesizing various oxide materials.

Why this method? [Benefits of sol-gel method]

The sol gel method provides excellent control over the texture, chemical composition and morphology of the materials. It allows uniform incorporation of dopants

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through impregnation at molecular level. (5)

Different steps in sol-gel method are –

① Selection of precursors: The process starts with suitable precursors, usully metal alkoxides or inorganic metal salts, which supply the required metal ions for oxide formation.

② Preperation of solution: The precursor is dissolved in an appropriate solvent, either alcohol or water to form a homogeneous solution.

③ Hydrolysis reaction: Water reacts with the precursor, breaking metal-organic bonds and forming metal-hydroxyl (M-OH) groups. This determines the initial structure of sol.

④ Condensation: The hydroxyl groups undergo condensation reactions, forming M-O-M bonds. This results in a three dimensional network and produces a colloidal suspension called a sol.

⑤ Gelation: As condensation continues, the sol transforms into a gel, where solid particles form an interconnected network filled with solvent.

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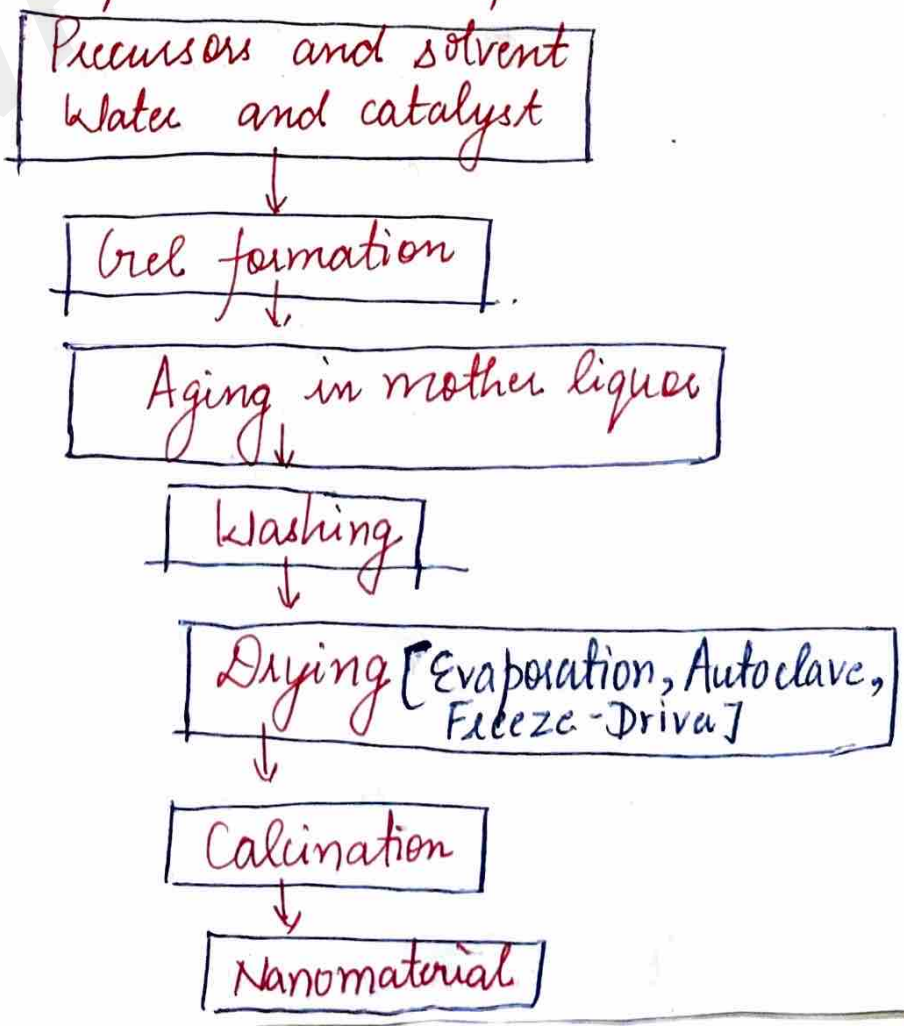
⑥ Aging of the gel: The wet gel is kept ~~int~~ in its mother liquor for a certain time.

⑦ Washing: The gel may be washed to remove unreacted precursors, by-products and impurities.

⑧ Drying: The solvent is removed from the gel by drying to obtain a dry gel.

⑨ Calcination: The dried gel is heated to remove residual organic components and to obtain the synthesized nanomaterial.

The following diagram represents all steps-



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